CPSA 6 (b)(1) Cleared

No Mfrs/PrvtLblrs or Products Identified

Excepted by

Firms Notified,

Comments Processed.

Meeting Log

Subject: Meeting with representatives from GRI, AHAM, Battelle Labs, and Maytag concerning CO emissions from gas-fired ranges/ovens

Meeting Date: June 11, 1996

Place of Meeting: CPSC, East-West Towers, Room 410 B/C

Date of Entry: June 19, 1996

Source of entry: Tim Johnson, ESEE

Commission Attendees:

Tim Johnson, ESEE
Elizabeth Leland, EC
Laureen Burton, EH
Don Switzer, ESEE
Christopher J. Brown, LSEL
Robert Franklin, EC
Chuck Smith, EC

Non-Commission Attendees:

Ted Williams, Gas Research Institute (GRI)
Jim Reuther, Battelle Labs
Irwin Billick, Consultant/GRI
Wayne Morris, AHAM
Isaac Sargunam, Maytag Cleveland Cooking Products
Jim Ranfone, AGA
Sam Cristy, PSL

Staff Comment:

Staff has not studied or performed a critique on the report that was presented to CPSC staff in this meeting (report titled: Critique of ANSI Z21.1 Standard for CO Emissions From Gas-Fired Ovens and Ranges) to verify any results presented. CPSC staff neither concurs or disagrees with the results/opinions expressed by AHAM, GRI, or Battelle Labs, presented in this meeting.

Summary of Meeting:

The meeting was requested by Mr. Wayne Morris, AHAM. Mr Morris started the meeting by stating that AHAM is concerned about press reports on CO emissions from gas ranges/ovens. Both Mr. Morris and Ted Williams (GRI) expressed an interest in learning more about CO emissions from gas ranges/ovens, possibly working with CPSC on this issue. The main topic of the meeting was a report done by Battelle Labs for GRI. The report was a critique of the CO emissions portion of the ANSI Z21.1 standard (gas fired cooking appliances).

Discussion:

A DRAFT report was distributed to all meeting participants and is attached to this meeting log. The DRAFT report is titled: Critique of ANSI Z21.1 Standard For CO Emissions From Gas-Fired Ovens and Ranges

Mr Reuther, Battelle labs, then proceeded to go through this report is some detail in the meeting. Some of the main points made were:

- The basic rationale, and assumptions that were used to form the CO emissions requirement/testing procedure in the standard go back 70 years to 1925. it was felt that due to the increased awareness/concern on the part of the general public about CO levels indoors, brought on by CO detectors, it is imperative to reassess the CO emission requirements in Z21.1 for gas ranges/ovens.

- The objective if this report was to document and assess the criteria first used by the AGA and ultimately ANSI to establish a limit for CO emissions from gas-fired ranges/ovens. A further objective was to critique the methodology used for the measurement of CO emissions.

- The 800 ppm "air-free" requirement was assessed in the report. A concern that GRI, AHAM have is that this air-free requirement is being interpreted by various parties to mean that an appliance can produce up to 800 from the exhaust port of the appliance, which is not the case.

- The ANSI standard appears to be valid today. The protocol used in the Z21.1 standard exaggerates normal oven/range use/misuse, and fosters CO emissions. However, if the 800 ppm air free requirement is met, ambient CO levels are expected to be within acceptable exposure limits. As a result, GRI asserted that ovens/ranges that comply with this standard do not pose a public safety or health threat.

- It was shown via a mass balance equation that used to appear in the standard (it was deleted from the standard in 1982) that many of the variables that were used in this equation (to produce the 800 ppm air free number) are based on 1925 data. The point that was made was that these assumptions lead to an air-free requirement (800 ppm) that is conservative. Variables discussed included thermal loading, number of air changes per hour, outdoor CO level, 1 hour allowable CO levels, etc

- A "built in" safety factor is included in the standard. The point was made that if a range/oven, certified to ANSI Z21.1, is used in a worst case scenario, i.e. as a space heater, the temperature in the living space will become unbearably hot before CO reaches a serious level in that living zone. In other words, it was asserted that the consumer will turn off the appliance due to elevated temperatures before CO levels become dangerous.

attachments (1)

GRI-96/DRAFT

CRITIQUE OF ANSI Z21.1 STANDARD FOR CO EMISSIONS FROM GAS-FIRED OVENS AND RANGES

TOPICAL REPORT

(August 1995 - June 1996)

Prepared by

J. J. Reuther

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Contractor Project No. N5714-0032 (3746)

For

GAS RESEARCH INSTITUTE

Contract No. 5091-251-2212

GRI Project Managers
I. Billick and T. Williams
Environment and Safety Research Department

June 1996

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RESEARCH SUMMARY

Title	Critique of ANSI Z21.1 Standard for CO Emissions From Gas-Fired Ovens and Ranges
Contractor	Battelle GRI Contract Number: 5091-251-2212
Principal Investigator	J. J. Reuther
Report Period	August 1995 - June 1996 Topical Report
Objectives	To document and assess the criteria first used by the American Gas Association, and ultimately the National Standards Institute (ANSI), to establish a limit for carbon monoxide (CO) emissions from gas ovens/ranges (Z21.1); and to formulate a methodology for the measurement of CO emissions from ovens/ranges which is representative, reproducible, and reliable.
Technical Perspective	Because of the increased use of CO detectors, and association of the reason for alarms with combustion sources, gas-appliance manufacturers, users, and regulators need to know, with certainty, the adequacy of public safety/health standards for CO, how to accurately/reproducibly measure CO, and the actual and possible levels of CO in the flue and in the indoor air during normal operation and misuse, how they relate, and if they comply with standards.
Results	The basis for, and allowable CO limit set by, the original CO standard remain valid today. They are conservative compared to Consumer Product Safety Commission (CPSC) and Underwriters Laboratories (UL) standards. The Z21.1 protocol exaggerates normal oven/range use/misuse, and fosters CO emission. However, if the 800 ppm flue-CO limit is met, ambient CO levels are expected to be within acceptable exposure limits. As a result, ovens/ranges that comply with this standard do not pose a public safety or health threat.
Technical Approach	Task 1 documented the basis, rationale, and assumptions used since 1925 to limit CO to "0.08 percent in an air-free sample of flue gas" (800 parts-per- million, ppm). Task 2 examined the extent to which these criteria were and are discriminating and defensible, or if other criteria are now more appropriate and representative. Task 3 determined whether a simple technique can be used to measure oven/range CO in the field, and reliably relate data to ambient levels.
Project Implications	The intent is to provide a proper and fair evaluation of the impact gas oven/range CO emissions on indoor air quality. GRI is working in cooperation with CPSC, UL, and the gas industry to ensure the continued safety, reliability, and affordability of gas appliances in a changing regulatory environment. GRI Project Managers: Irwin Billick and Ted Williams

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TOPICAL REPORT

on

CRITIQUE OF ANSI Z21.1 STANDARD FOR CO EMISSIONS FROM GAS-FIRED OVENS AND RANGES

to

GAS RESEARCH INSTITUTE
June 1996

1.0. INTRODUCTION

Because of the increased use of carbon monoxide (CO) detectors, and the tendency to associate the reason for alarms with combustion sources, gas-appliance manufacturers, users, and regulators need to know, with certainty, information on the following issues to make informed decisions:

- The adequacy of current appliance standards in place to protect public safety and health,
- How to accurately/reproducibly measure gas-appliance emissions in the lab/field, and
- The actual/possible levels of emissions in gas-appliance flues and in residences during normal operation and misuse, how they relate, and if they comply with standards.

This report chronicles efforts on these issues, with the gas appliance of interest the oven/range. Although focussed on CO and gas ovens/ranges, the results of this program are relevant to other trace emissions, such as nitrogen dioxide (NO_2), and other gas appliances, such as space heaters.

2.0. TECHNICAL BACKGROUND

Although CO emissions from gas ovens/ranges have been managed for ~70 years [1-3], the recent availability of residential electronic detectors for CO, conforming to Underwriters Laboratories (UL) Standard 2034 [4], has heightened consumer awareness of the possible presence of CO in the indoor environment. It is now imperative to evaluate, with confidence, the impact of the gas oven/range on indoor CO levels. This can be accomplished by assessing the appropriateness of criteria setting CO limits (American National Standards Institute, ANSI Z21.1), reviewing alternative standards proposed by the Consumer Product Safety Commission (CPSC), and evaluating the confidence with which oven/range-flue and ambient CO emissions can be determined to be in compliance.

3.0. PROGRAM OBJECTIVES

The three overall objectives of this program were as follows:

- To document the criteria and history of the CO standard for gas ovens/ranges,
- To assess the technical merit of criteria used to establish CO standards, to determine if these CO standards were, and are, appropriate for appliance certification, and as a field indicator of CO exposure, and
- To formulate a methodology for the measurement of CO emissions from ovens/ranges in the field, which is representative, reproducible, and reliable.

4.0. TECHNICAL APPROACH

Task 1 consisted of documenting the basis, rationale, and assumptions used since 1925 to establish the current CO emissions standard for an air-free sample of oven/range flue gas.

Task 2 consisted of examining the extent to which criteria used to set the CO limit were, and are, discriminating and defensible, or if other criteria are now more appropriate and representative.

Task 3 consisted of determining whether a "single-point", or "first-order", technique could be established by which to measure CO emission levels in the flues of ovens/ranges operating in the field, and to relate these data to ambient levels. The technique is intended for routine checking, or in investigating the involvement of a oven/range in a situation where ambient CO might be a problem.

The output of Task 3 is not a recommendation for an ambient or flue-gas CO emissions-limit for ovens/ranges. Rather, it is an investigation of methodology for relating ambient-exposure levels CO to appliance-flue levels. Included in this rationale are estimated levels of confidence allowed in the measured flue data, and in the extent to which they characterize the likelihood any operating oven/range might create some level of CO exposure. The single performance indicators considered were either the CO concentration in the ambient, or in the flue. The measurement is qualified to decide whether CO emissions from ovens/ranges might, or might not be, a safety or health concern, and whether a simple measurement is sufficient to characterize the situation, or whether more measurements are required to characterize the influence of the range/oven on the indoor environment.

5.0. RESULTS AND DISCUSSION

Progress on each task is reported next, using information from several sources [1-25].

5.1. Historical Review of ANSI Z21.1 Oven/Range Standard for CO

The current ANSI Z21.1 standard for CO from residential ovens/ranges is stated as follows [3]:

- "An appliance shall not produce a concentration of carbon monoxide in excess of 0.08 percent in the air-free sample of the flue gases when the appliance is tested in a room having approximately normal oxygen supply".

The ANSI CO limit concentration of "0.08 percent" corresponds to 800 parts per million, ppm. "Air-free" means that the as-measured concentration of CO in the flue, which is typically diluted by the excess air used for combustion, has been normalized to an "oxygen-free", or "0%-O_2", basis [5,6]. As-measured carbon dioxide (CO_2) or O_2 concentrations are used to account for this dilution.

For oven/range emissions, O_2-free CO is typically ~5-times the as-measured CO, depending on the amount of excess air [5,6]. The ambient exposure-limit concentration for CO is the as-measured concentration, which has diluted the oven/range exhaust into the room volume.

Whereas the current ANSI Z21.1 standard does not give the basis or justification for the CO level, the original 1925 standard was clearly safety and health-based, as follows [1]:

- "Assuming that the human system can be subjected to a concentration of 0.01% with a reasonable degree of regularity without injurious effects, it appears that the acceptance of this statement governs to a large extent the selection of our standard".

An historical review of CO standards revealed that the current "0.08%" limit was not specified in the original 1925 standard [1]. Instead, a CO limit of 0.075% (750 ppm), O_2-free, was derived from the numerical information given in the following statement, all of which were hypothetical and assumed, and which may or may not be representative of typical residential conditions:

- "This requirement shall be deemed met when a concentration not in excess of 0.01% is produced in a room of 1,000 cubic feet content with 4 air changes occurring during the combustion of an amount of gas liberating 60,000 Btu".

These words were translated into the following equations:

$$CO_a = \frac{CO_x * F * V_p * (1 - e^{-Nt})}{N * V} \qquad \text{(EQ1)}$$

where:

CO_a	=	Allowable 1-hour ambient CO exposure level (0.010%, as measured),
CO_x	=	Allowable appliance-flue CO exhaust level (0.075%, dry, O_2-free),
F	=	Firing rate of gas appliance (60 KBtu/hr),
V_p	=	Volume of dry, O_2-free natural-gas combustion products (8.52 ft^3/KBtu),
V	=	Volume of the room into which CO is emitted (1000 ft^3),
N	=	Number of room air changes per hour (4 hr^{-1}),
t	=	Time interval (1 hr), and
e	=	Naperian logarithmic base (2.72),

or, in simplified form:

$$CO_a = 0.0147 * CO_x * V_p \qquad \text{(EQ2)}$$

The numerical values for these parameters were justified in 1925, as follows:

- "The number of air changes in the room is undoubtedly affected to a large extent by the rate at which gas is burned. The ordinary cabinet range, burning normally about 60,000 Btu per hour, would soon produce an unbearable temperature in a 1,000 cu. ft. room. Consequently, if gas should be burned at this rate for any appreciable period, doors and windows would be opened to cause a rapid circulation thru the room. 1,000 Btu will raise the temperature of 1,000 cu. ft. of air approximately 50°F. If we assume that only 10% of the heat liberated by the burning gas is absorbed by the room atmosphere, and that the temperature of incoming air is not increased more than 75°F, the air in a 1,000 cu. ft. room must be changed four times per hour, where the gas is burned at the rate of 60,000 Btu. Therefore, the condition we must guard against is the production of CO in sufficient quantities to raise the concentrations of the room atmosphere above .01%. This may be done by limiting the amount of CO in the combustion products to .075%."

In 1932, EQ2, the simplified version of EQ1, was added to the Z21.1 standard. In 1982, both the original statement and the two equations were replaced with the current statement. No reason was discovered for this revision, or why CO_x was changed from .075% (750 ppm) to 0.08% (800 ppm).

In addition to reviewing how the CO standard was defined, also reviewed was how CO emissions from ovens/ranges were to be measured to determine compliance. An historical review of CO measurement methodologies is given in Table 1.

TABLE 1. HISTORICAL REVIEW OF Z21.1 CO MEASUREMENT METHODOLOGIES

YEAR	NO. OF BURNERS ON?	BURNER FIRING RATES (KBtu/hr)	LOAD?	SAMPLING HOOD?	SAMPLING HOOD HEIGHT	RANGETOP BURNER WARM UP TIME (minutes)	OVEN BURNER WARM UP TIME (minutes)
1925	All (~4) Rangetop & Oven	Ranges @ Maximum Ovens @ 10 KBtu/ft^3	Yes	Yes	@ Grate Height	5	15
1990s	All (~4) Rangetop & Oven	Ranges @ Maximum Ovens @ Maximum	Yes	Yes	@ Maximum CO_2	5	5

The differences between how CO was to be measured in the 1925 standard, and now, concern:

- The rate at which the oven burner is to be fired,
- How high the sampling hood is to be elevated over the range surface, and
- How long the oven burner is to be fired before a flue sample was taken.

In the original standard, concerned was expressed that sampling-hood position effected the CO measured, but not for the oven-burner firing rate or warmup time. As will be discussed in Section 5.3, these sampling protocol characteristics all have an effect on the amount of CO that is eventually measured. That elements of the sampling protocol can significantly influence the concentration of a trace emission observed has been convincingly demonstrated [5,15].

One other aspect of the CO measurement protocol (since at least 1959) must also be noted for future reference. The requirement concerns heating capacity, or the minimum time required for an oven and broiler to heat to a specific temperature, which is stated, as follows:

- Oven: Room temperature to 400 °F in 10 minutes, and
- Broiler: Room temperature to 530 °F in 12 minutes.

The importance of these "heating-up" requirements will also be discussed in Section 5.3.

5.2. Validity of Assumptions in ANSI Z21.1 Standard for CO

As shown in Section 5.1, several assumptions were made in 1925 to characterize the conditions under which CO emissions from ovens/ranges might pose a safety or health threat. The obvious ones dealt with quantifying the allowable CO exposure limit, the conditions within a residence, and the operation of the gas appliance. Two assumptions, however, are implicit in EQ1, and not completely obvious. Together, they are most important to present and future regulations.

First, assumed the **most critical factor governing the use and limitations on the use** of an oven/range was **room temperature**. That is, these gas appliances were being **used inappropriately as space heaters**. This assumption rationalized requiring a test-firing rate of 60 KBtu/hr (all rangetop/oven burners firing @ maximum), and is representative of some real-world practice. Currently, an estimated 12% of US households use their gas oven/range for space heating about 2-3 days a winter [7]. It is not unreasonable to assume that this practice was greater in 1925. Under this mode of (mis)operation, the oven/range poses a worst-case threat, as it would be caused to emit combustion products into the residence for the longest, continuous length of time. Under normal, average operation, the oven/range is used only about 1 hour per day for cooking [7].

Second, because CO is a colorless, odorless, and tasteless gas, a safeguard was built into the original CO standard, involving a surrogate measure of mis/over-use: the (over)heating of the room by the oven/range. The selection of a firing rate of 60 KBtu/hr, a room volume of 1000 ft^3, an air exchange rate of 4 hr^{-1}, and, **most important**, a **thermal efficiency for the oven/range acting as a space heater of 10%**, were intentional. By doing so, ANSI built a **thermal indicator** into the standard of a 75 °F temperature rise in 1 hour, which would be noticeably uncomfortable. Using these values in EQ1, the 750 ppm, O_2-free, limit for CO in the oven/range flue was set. Under these prescribed conditions, the following occurs:

- If the oven/range emitted 750 ppm, O_2-free, in the flue, the allowable 1-hour ambient CO exposure level of 100 ppm (as measured) would be reached in 1 hour, which would be sensed by the resident by an unbearable temperature rise of 75 °F.

Using overheating was a practical, prudent means by which to alert residents that a harmful CO level was being approached. Recent field data on CO levels in residences were used to demonstrate that such overheating occurs long before CO levels increase to a dangerous level (see Appendix 1) [8].

In the ~70 years since the first CO standard, changes have occurred in health-effects criteria, gas-appliance design, and residence volume/ventilation characteristics, which are significant.

Health-effects criteria are critically important, because they define the purpose and scope of an indoor-air quality standard, regardless of how and where the trace constituent is measured. The 1925 standard only eludes to "injurious effects" upon exposure to 100 ppm CO, without specifying exposure time, or what the effects are, which could be headache, nausea, unconsciousness, or death. Such is not the case for the current UL standard for CO detectors. The difference is significant.

UL 2034 states that a CO detector shall provide a warning at or below that CO dose/exposure level which results ~10% carboxyhemoglobin (COHb). Although not expressed nor recognized in such terms, the 1925 standard also defines a COHb dose/exposure limit. This dose/exposure limit is the time-average concentration of CO generated by a oven/range over the 1-hour interval, as CO emissions increase from 0 to the 100 ppm CO_a limit. This average CO_a is the integral of CO_a over 1 hour (EQ1), and equals 75 ppm. Using UL calibrations relating constant CO level to COHb, 55 ppm CO for 1 hour results in a COHb of ~5% [4,9]. Hence:

- With regard to allowable carboxyhemoglobin levels, the past and current CO standard for ovens/ranges is ~50% more conservative than the current UL standard for detectors, implying that the warning based on overheating associated with oven/range operation would be sensed before the activation of the CO detector required by UL.

The CPSC recently proposed a model, related to EQ1, to characterize the impact on indoor air quality of NO_2 emissions from unvented space heaters [10]. This model, and its input parameters, if adapted to CO, were used here as a means by which to assess the technical merit of the original model and limit for CO emissions from oven/ranges.

The proposed CPSC model equation is as follows, with $\bar{NO}_2$ having been replaced by CO:

$$CO_x = \frac{CO_a * (N + K) - (N * C_o)}{Q * dT} \qquad \text{(EQ3)}$$

where:

CO_x	=	Allowable appliance-flue CO exhaust level (*4420 for ppm, O_2-free),
CO_a	=	Allowable 1-hour ambient CO exposure level (ppm, as measured),
N	=	Number of air changes per hour in room (hr^{-1}),
K	=	Decay rate of species (hr^{-1}),
C_o	=	Outdoor ambient CO level (ppm, as measured),
Q	=	Thermal loading of room (Btu/hr-ft^3-°F), and
dT	=	Indoor/outdoor temperature difference (°F).

Table 2 presents a comparison of ANSI and CPSC model input parameters, and the values assigned to each. Note that K = 0 for CO, and is, therefore, "Not Specified, NS".

TABLE 2. ANSI AND CPSC MODEL INPUTS FOR CO OVEN/RANGE EMISSIONS

INPUT PARAMETER		ANSI MODEL	CPSC MODEL	CPSC DATA IN ANSI MODEL
Q:	Thermal Loading, Btu/hr-ft^3-F	0.020	0.045 (10)	0.045
E:	Thermal Efficiency, %	10	NS (90+) (11)	90
dT:	Temperature Difference, °F	75	31 (10)	31
N:	Number of Air Changes, hr^{-1}	4.0	0.5 (10)	0.5
F:	Firing Rate, KBtu/hr	60	NS (≤40) (11)	60
V:	Room Volume, ft^3	1000	NS	1000
t:	Time Interval, hr	1	1	1
CO_o:	Outdoor CO level, ppm	NS	1 (13)	NS
CO_a:	1-hr Allowable ambient CO, ppm	100	25 (10)	25
CO_x:	Allowable exhaust CO, ppm	800	1040	560

A review of the magnitude and significance of each model parameter is given next.

With regard to **thermal loading**, ANSI assumed a value ~50% lower than the CPSC. According to the CPSC, thermal loadings below 0.045 Btu/hr-ft^3-°F are not representative of a residence, and would result in CO_x values that are artificially high. From the ratio the thermal loadings, the Z21.1 CO_x of 800 ppm may be **high by a factor of ~2.**

With regard to **thermal efficiency**, a 10% efficiency was assumed in 1925, implying that ovens/ranges were very inefficient space heaters. Although data on such have not been reported (or measured), the thermal efficiency of an oven/range operating as a space-heater should approach that of a space heater, ~90% (11). In any event, 10% is unrealistic. Hence, the low thermal efficiency assumed in 1925 may have made the 800 ppm CO_x **low by a factor of ~9.**

With regard to **temperature difference**, Z21.1 assumed a temperature rise of 75 °F. If the indoor temperature were to increase 75 °F, to not become unbearable, the outdoor temperature would have to be near ~0 °F. The CPSC assumed an outdoor temperature of 41 °F, and a temperature rise of 31 °F, to 72 °F. This assumed value makes the Z21.1 CO_x of 800 ppm **low by a factor of ~2.**

With regard to **number of air changes**, 4 hr^{-1} was selected to maintain a comfortable temperature, and may have been representative of homes in the 1920s. It probably did not represent air exchange between the entire house and the outdoors, but instead, the air exchange between the kitchen and the rest of the house. On the other hand, CPSC assumed air exchange between the room and the outdoors at a rate of 0.5 hr^{-1}, which is probably indicative of today's weatherized homes [10]. The ANSI/ASHRAE standard for minimum number of air changes is 0.35 hr^{-1} [12]. Hence, Z21.1 set CO_x **high by a factor of ~8**, which is probably realistic in accurately representing the role of the rest of the house as a heat sink and as a diluting volume.

With regard to **room volume**, Z21.1 assumed a typical kitchen was 1000 ft^3. Data are not available to refute the appropriateness of this value, although kitchens today may be larger. One fact for certain is that kitchens now rarely have doors, which would effectively increase their "volume" because they would be connected directly to other rooms. This would effectively increase the number of air changes. The CPSC model is independent of room volume, because it includes this parameter in the thermal-loading term of its model equation (EQ3).

With regard to **firing rate**, Z21.1 assumed a worst case: all range burners firing at maximum (4*10 KBtu/hr), plus the oven burner firing at 20 KBtu/hr, for 60 KBtu/hr. This firing rate is ~50% higher than a typical space heater, ~40 KBtu/hr [11]. Hence, the Z21.1 CO_x may be **low by ~50%.**

With regard to the **time interval**, the 1-hour exposure period assumed by Z21.1 and the CPSC is a short-term exposure period related to the duration at which health effects are first witnessed. Data on the household usage of gas appliances indicate that less than 2.5% of owners use their oven/range more than 1 hour at a time, on average. Hence, the 1-hour interval may relate well to health-effects thresholds, but not to normal usage.

With regard to **outdoor CO**, Z21.1 did not consider the impact of outdoor CO on indoor CO. Recent studies on air quality indicate that indoor background $\overline{CO}$ levels average ~1.6 ppm, outdoor CO levels average ~1.0 ppm, and outdoor CO accounts for about half the indoor CO [13]. By assuming an effective indoor CO level of zero, Z21.1 underestimated the impact of indoor-generated CO.

With regard to the **1-hour CO exposure** concentration allowable before adverse health effects occur, CO_a, the CPSC recommends 25 ppm over 1 hour, 4-times lower than assumed by Z21.1, which is estimated from more current health-effects data [10]. For comparison, the National Ambient Air Quality Standards for CO set by the US Environmental Protection Agency are 35 ppm for 1 hour, and 9 ppm for 8 hours [10]. Hence, Z21.1 CO_x may be **high by a factor of ~4.**

Finally, with regard to **allowable CO in the gas-appliance exhaust**, CO_x, the sought-after number, an attempt was made to compare the output of the Z21.1 and CPSC models, separately, and with the interchange of modern CPSC data for thermal loading, thermal efficiency, air change, and allowable ambient exhaust CO into the Z21.1 model equation (EQ1). Because EQ1 and EQ3 do not contain the same terms, the interchange of EQ3 data into EQ1 is not strictly valid. However, It was conducted in the interests of qualitatively comparing the results of the two available models. The results are given in the last row of Table 2, and are as follows:

- The 1994 CPSC space-heater model for NO_2, if adapted to ovens/ranges and CO using CPSC-recommended input data, requires CO_x = ~1040 ppm, O_2-free, ~30% more than the 800 ppm required by ANSI for ~70 years, using the 1925 Z21.1 model and data.
- If 1994 CPSC input data are used in the 1925 Z21.1 model, CO_x = ~560 ppm, or ~30% less than the 800 ppm maximum allowed for ~70 years.

These comparisons between estimations for CO_x based on the original, current, and proposed models and data clearly indicate the following:

- The original Z21.1 model and limit for oven/range CO emissions are considerably more conservative than either the CPSC model, or the basis for the UL detector limit.

5.3. Basis for Monitoring CO Levels in the Field

The objective of this task was to determine whether a "simple, single-point" methodology could be established for measuring CO in oven/range flues in the field, and relating these concentrations to ambient levels to assess safety and health, which was **representative, reproducible,** and **reliable.**

With regard to **representativeness**, Table 3 compares how original/current Z21.1 standards require operation of ovens/ranges for CO certification, compared to normal operation and misuse.

TABLE 3. COMPARISON OF OVEN/RANGE OPERATING PRACTICES

PRACTICE	NO. OF BURNERS ON?	RANGETOP and OVEN FIRING RATES	RANGE and OVEN LOAD?	SAMPLING HOOD?	RANGETOP BURNER WARM UP TIME (minutes)	OVEN BURNER WARM UP TIME (minutes)
Z21.1 (1925)	All Rangetop + Oven(door closed)	Ranges @ Maximum Ovens @ 10 KBtu/ft^3	Yes/No	Yes	5	15
Z21.1 (current)	All Rangetop + Oven(door closed)	Ranges @ Maximum Ovens @ Maximum	Yes/No	Yes	5	5
NORMAL USE	1-2 Rangetops + Oven(door closed)	Ranges < Maximum Oven < Maximum	Yes/No	No	30+	60+
MISUSE	4 Rangetop + Oven(door open)	Ranges @ Maximum Ovens @ Maximum	No/No	No	120+	120+

With regard to the **number of burners on** and **burner firing rate**, past and present Z21.1 standards recreate the misuse of an oven/range as a space heater, designating firing-rate at 60 KBtu/hr. In 1925, rangetop and oven burners averaged ~10 and ~22 KBtu/hr each, respectively, slightly exceeding the 60 KBtu/hr model firing rate [1,2]. Today, oven/range burners average ~18/~9 KBtu/hr each, respectively, for a ~54 KBtu/hr total [11]. The difference represents a ~10% bias against modern ovens/ranges achieving Z21.1 compliance. With regard to ovens, Z21.1 specified a volumetric firing rate of ~10 KBtu/ft^3-hr in 1925 [1]. Today, ovens average ~4 KBtu/ft^3-hr [14]. Hence, operating practices today do not match original Z21.1 practice by a factor of ~2, again biasing the results against an oven/range achieving Z21.1 compliance.

These two departures beg the question of whether a standard is fair if it uses "average" performance characteristics. In the case of firing rates, the "variability" is >10%. The precision of any CO standard would probably benefit from accounting for such variations in the population of ovens/ranges.

Other notable differences among Z21.1 operating practice, normal use, and misuse are:

1) The oven door is closed during CO testing and use, but is probably open during misuse.

2) The range has a load during CO testing and use, but probably does not during misuse.

3) A sampling hood is present during CO testing, but is not during use/misuse.

4) Burner warmup time is 5 minutes during CO testing, but $\leq$12 minutes during Z21.1 thermal-performance rating, and ~30-120+ minutes during use/misuse.

5) During normal use, firing rates vary/cycle; during misuse, they are constant at maximum.

The significance of these differences on CO production are as follows:

1) Oven CO with the door closed is probably higher than with the door open (8).

2) Range CO with a load is as much as 2-times higher than without a load (5,15).

3) Range CO with a sampling hood is probably higher than without a hood (1,19).

4) Oven/range CO after 5 minutes warmup is ~5-times higher than at 1+ hour warmup (8,16,18).

5) Oven/range CO is lower when burners cycle than when firing constant maximum rate (17).

The net result these differences can be characterized by the following statement:

- Departures from normal oven/range operation during Z21.1-CO testing cause CO to be produced at significantly higher levels than during normal use and misuse, by as much as a factor of 5, which grossly misrepresents the intended use of the oven/range, but which effectively builds a margin of safety into the Z21.1 CO standard.

With regard to **reproducibility**, despite its current importance, the extent to which CO emissions from ovens/ranges can be reliably measured has only recently begun to be reviewed (5). To build on this start, a CO emissions data base was developed, analyzing data from three major sources. The first was the technical literature, including CO emissions data reported in 1925/6 (1,2). The next was an international interlaboratory program conducted to measure the reproducibility of NO_2 emissions, but which also included CO data (5). The last was recent oven/range CO audit data, provided especially for this project by the Association of Home Appliance Manufacturers (AHAM).

In this analysis, all emissions data were assumed accurate, and not affected by elements of the CO sampling/measurement protocol, although some bias is expected, as observed for NO_2 [5,15]. Tables 4 lists the results on how reproducibly CO emissions can be measured by one laboratory on the same appliance: a gas range. CO emissions data deemed appropriate if they were determined: a) in triplicate, at least; b) on the same model residential rangetop burner; c) at maximum firing rate; d) under well-tuned (blue flame) conditions; and e) using the Z21.1 measurement protocol.

Intralaboratory reproducibility data were obtained on 4 different types of agencies (research laboratory, university, range manufacturer, and commercial testing company), making the measurements in 3 different settings (lab, factory, and field), spanning over 20 years. Altogether, ~640 data points were obtained from 19 different agencies. These agencies will not be identified by name, except to state that over half were participants in the international interlaboratory study [5]. Intralaboratory CO data are listed as a function of year measured, from past to present.

The following observations were made regarding average intralaboratory reproducibility:

- In a research-lab setting, it is about ±17%,
- In a university setting, it is about ±21%,
- In a factory setting, it is about ±33%,
- In a field setting, it is unknown,
- Over ~20 years time, has not effectively changed, and
- Overall, is about ±20%, ± 11 percentage points.

In summary, rangetop CO emissions appear measurable to within an uncertainty of ~ ±20%. This uncertainty is somewhat less if the measurement is conducted by a research agency in a lab. It is somewhat more if measured by a manufacturer in factory setting. Unfortunately, no data were found on the reproducibility to which CO emissions can be measured in the field. Apparently, such critical measurements were not part of these test programs [8,18]. Intralaboratory reproducibility in the field is probably ≥ ±20%. Finally, the ability to reproduce CO data has not changed with time.

This analysis was repeated for oven CO, with the only data found meeting the aforementioned criteria provided by AHAM. Measurements by 4 manufacturers in 1995 indicated that oven CO intralaboratory reproducibility (108 data points) averaged ±38%, ~50% higher than that for ranges.

TABLE 4. INTRALABORATORY REPRODUCIBILITY OF RANGETOP CO

AGENCY TYPE	TEST SETTING	DATA POINTS	STANDARD DEVIATION (%)	DATE (year)	Reference (#)
Research	Lab	8	± 17	1974	5b[7]
Research	Lab	26	± 11	1983	5b[8]
University	Lab	57	± 12	1984	5b[9]
University	Lab	36	± 14	1984	5b[9]
University	Lab	45	± 16	1984	5b[9]
University	Lab	45	± 43	1984	5b[9]
Research	Lab	33	± 6	1985	5b[10]
Research	Lab	25	± 7	1985	5b[10]
Research	Lab	58	± 8	1985	5b[10]
Research	Lab	3	± 24	1987	5b[11]
Research	Lab	3	± 11	1989	5b[3]
Research	Lab	3	± 26	1989	5b[3]
Research	Lab	3	± 32	1989	5b[3]
Research	Lab	18	± 23	1989	5b[L1]
Research	Lab	18	± 20	1989	5b[L2]
Research	Lab	18	± 23	1989	5b[L3]
Research	Lab	18	± 21	1989	5b[L4]
Research	Lab	18	± 35	1989	5b[L5]
Research	Lab	18	± 19	1989	5b[L6]
Research	Lab	18	± 5	1989	5b[L7]
Research	Lab	18	± 15	1989	5b[L8]
Research	Lab	18	± 12	1989	5b[L9]
Research	Lab	18	± 13	1989	5b[L10]
Research	Lab	18	± 12	1989	5b[L11]
Research	Lab	18	± 14	1989	5b[L12]
Manufacturer	Factory	6	± 49	1995	AHAM[a]
Manufacturer	Factory	3	± 18	1995	AHAM[b]
Manufacturer	Factory	42	± 39	1995	AHAM[c]
Manufacturer	Factory	14	± 19	1995	AHAM[e]
Manufacturer	Factory	32	± 29	1995	AHAM[f]
Testing	Field	144	?	1995	8,18
AVERAGE	ALL	644	± 20	20+ years	This Study

Last, the reproducibility to which different agencies can measure CO emissions from a common gas appliance was assessed in an international interlaboratory program in which 15 participants measured CO from the same 3-different rangetops, in triplicate, using the same sampling paraphernalia [5]. The resulting **inter**laboratory reproducibility was about ±40%.

In summary, with regard to reproducibility, CO emissions are measured, and known, to within about ±30%. The Z21.1 CO limit would be better expressed as 800 ± 240 ppm, or 560-1040 ppm.

Considered last was the **reliability** with which flue-CO might predict ambient-CO. The analysis began by documenting the average flue concentrations of CO reportedly emitted by gas ovens/ranges in various studies. The criteria used to deem the appropriateness of these flue-CO data were the same as those invoked earlier in reviewing intralaboratory CO data.

Results are listed in Table 5. Oven/range CO levels are listed as **arithmetic averages**, as reported by each paper. Although the significance of arithmetic averaging will be discussed later, suffice it to say here that it yields artificially high averages. When available, data are listed for the number of models tested, and the percent of the appliance-model population this number might represent. Under compliance are the percentages of models reported to emit ≤800 ppm CO, O_2-free.

TABLE 5. REPORTED OVEN/RANGE CO EMISSIONS DATA

VINTAGE (YEAR)	NO. OF MODELS	AVERAGE OVEN CO (ppm, O_2-free)	AVERAGE RANGE CO (ppm, O_2-free)	POPULATION REPRESENTED (%)	COMPLIANCE WITH ANSI (%)	REF.
1920s ('25)	10	38 ± 22	345 ± 369	90	80	1
1970s ('74)	18	104 ± 84	201 ± 70	90	100	19
1980s ('82)	2	185 ± 15	105 ± 35	--	100	20
1980s ('83)	4		290 ± 198		100	21
1980s ('84)	2	48 ± 7	225 ± 58		100	22
1980s ('85)	3	78 ± 21	201 ± 38		100	23
1980s ('89)	3		193 ± 90		100	5,15
1990s ('92)	20		286 ± 237		100	24
1990s ('95)	1	137 ± 33	150 ± 28		100	AHAM[b]
1990s ('95)	1	223 ± 105	231 ± 84		100	AHAM[c]
1990s ('95)	1	125 ± 51	61 ± 12		100	AHAM[e]
1990s ('95)	1	233 ± 55	193 ± 56		100	AHAM[f]
~70 years	66 models	'90s Avg: ~180	'90s Avg: ~160:			

The significance of the CO oven/range emissions data given in Table 5 is as follows:

- None of the arithmetically averaged O_2-free CO emissions data reported for ovens/ranges exceeds the Z21.1 limit of 800 ppm, the implied CPSC CO limit of 1040 ppm, or the hypothetical lower bound of the ANSI 800 ppm standard, 560 ppm, assuming $\pm$ 30% reproducibility.

Table 5 has replicated CO data measured under controlled research or test-lab conditions. Unreplicated oven CO data have recently been reported for field settings [8,18]. Because these data are current and unique, their meaning is timely. The 2 papers reporting these data were critically reviewed (Appendix 1, 2). Here, these data are used to answer the following critical question:

- To what extent does complying with the Z21.1 oven/range limit of 800 ppm, O_2-free, guarantee that the resident will always be exposed to a "safe" level of CO?

Table 6 contains the analysis of the field CO data of Tsongas [8] and Carnow [18]. Altogether, CO levels were measured in oven flues, under Z21.1 conditions, and in the ambient air at 138 sites. The arithmetic averages/standard deviations reported for as-measured oven CO are listed first.

TABLE 6. ANALYSIS OF OVEN/AMBIENT FIELD CO DATA

NO. OF OVENS (#)	AS-MEASURED OVEN CO [Arithmetic Average; Standard Deviation] (ppm)	AS-MEASURED OVEN CO [Geometric Average] (ppm)	O_2-FREE OVEN CO [Geometric Average] (ppm)	SITES CPSC-COMPLIANT [$\leq$25 ppm-1 Hr Ambient CO] (%)	REF.
60	410 $\pm$ 570	205	984	82	8
78	188 $\pm$ 177	105	504	100	18
20	166 $\pm$ 132	138	664	100	18

Two assumptions were made to analyze and interpret these data. First, when the absolute standard deviation exceeds an average, as it does in all 3 cases, geometric averaging becomes more statistically valid than arithmetic averaging (see Appendix 1 for more details) [25]. Second, from the references in Table 5, the ratio of ultimate-to-as-measured oven-CO_2, needed to normalize as-measured CO to O_2-free CO, was calculated as 12%/2.5%, for a normalization factor of 4.8 [5]. This CO_2 normalization factor was the same as measured in one of the field studies [18].

Geometric averages for as-measured and O_2-free oven-CO field data are listed next in Table 6. In the 60-site study, the O_2-free CO average for the oven population, 984 ppm, exceeds the Z21.1 standard of 800 ppm by ~25% [8]. The authors of this study contend that these data imply that ovens pose a health treat with regard to CO exposure. However, the steady-state ambient CO data collected at these same sites, and the sites in the other study [18], do not support this contention, as follows:

- Despite the average O_2-free oven-CO being ~25% greater than the Z21.1 800 ppm limit, 82% (49/60) of the sites had ambient CO levels of ≤25 ppm, the CPSC 1-hour limit.
- At those sites (122/138 = 88%) where the Z21.1 O_2-free oven-CO was ≤800 ppm, 100% had ambient CO levels of ≤25 ppm.
- At those sites (15/138 = 11%) where Z21.1 oven-CO exceeded even the CPSC CO limit of 1040 ppm, O_2-free, ~60% (9/15) had ambient CO levels ≤25 ppm.

These findings support the conclusion reached in Section 5.2 that the Z21.1 CO standard is conservative, or that it can be exceeded and still have the oven/range not generate ambient CO levels that would pose a safety or health threat. What must also always be factored into this analysis (from earlier in this section) is that the Z21.1 measurement protocol is biased toward promoting CO production. Despite this promotion of CO, ovens/ranges do not cause dangerous ambient-CO levels.

A final analysis was conducted to determine the extent to which CO measured in the flue, under Z21.1 conditions, correlated with the CO measured in the ambient, with the following result [8]:

- The extent to which Z21.1-flue CO correlates ambient CO is, at best, ~60%.

With all these analyses with regard to representativeness, reproducibility, and reliability in mind, the answer becomes clear to the question of how to measure, in a simple manner, CO in the field to determine if an oven/range is "safe". Based on the facts just presented:

- Measuring O_2-free CO in the flue, using the Z21.1 protocol, and limiting acceptable CO emissions to the Z21.1 standard of 800 ppm CO, O_2-free, is the most reliable means by which to determine if the CO emissions from that oven/range might impact the ambient indoor air quality to the extent that a safety or health threat is posed.

Of course, during the course of this single-point testing, any residential "systems" that impact ventilation, such as fans, doors, or windows, should be in their normal orientations.

6.0. Summary and Conclusions

The specific and overall conclusions reached by this program can be summarized as follows:

- The original 1925 CO standard for ovens/ranges, 750 ppm, O_2-free, revised to 800 ppm CO in 1982, had as its basis: a) the best-available data on CO exposure limits, firing rates, room volumes, and air exchange rates; b) the misuse of the oven/range as a space heater, and c) the misused oven/range causing the room to become unbearably overheated at the same time (1 hour) the ambient CO was increased to a level that might cause an "injurious" health effect.

- The underlying basis for, and allowable CO limit set by the original CO standard were valid and conservative in 1925, and remain so today, proven by the fact that: a) a CPSC model proposed for evaluating the impact on indoor air quality of space heaters uses similar input parameters; b) despite less-favorable input data, the proposed CPSC model estimates an allowable CO in oven/range flues that is ~30% higher than the original ANSI limit (1040 ppm CO); and c) even if an oven/range emitted only 1 ppm more CO than 800 ppm, the COHb level to which the resident's blood would be elevated, ~5%, is only half that allowed before a CO detector sounded a warning.

- Even though the Z21.1 method for measuring CO emissions in oven/range flues exaggerates the normal use and misuse of the oven/range, biasing emissions toward artificially high (≥2x) CO levels, and has a reproducibility of only ±30%, when CO emissions from ovens/ranges, as measured in the field using the Z21.1 protocol, are ≤800 ppm, 100% of the ovens/ranges comply with the 1-hour exposure level allowed by the CPSC, ≤25 ppm CO, 100% of the time, and comply >80% of the time if the CO emissions are ≤1040 ppm CO, the implied CPSC limit.

- Gas ovens/ranges do not pose a public safety or health threat with regard to CO emissions, a performance characteristic that can be validated using the current Z21.1 measurement protocol.

7.0. REFERENCES

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APPENDIX 1.

TECHNICAL REVIEW OF REFERENCE 8 (TSONGAS)

TECHNICAL REVIEW OF PAPERS BY TSONGAS: CO EMISSIONS FROM GAS-FIRED OVENS

October 6, 1995

A critical technical review is offered on the following papers (Tsongas 1: T1; Tsongas 2: T2):

T1. Tsongas, G. and Hager, W., "Field Monitoring of Elevated Carbon Monoxide Production from Residential Gas Ovens", ASHRAE IAQ, November, 1994.

T2. Tsongas, G., "Carbon Monoxide from Ovens: A Serious IAQ Problem", Home Energy, pp. 18-21, September/October, 1995.

These papers report CO concentrations measured in the kitchen and at the source (gas oven) in 60 apartments. The field data obtained are reproduced in the 6 left-most columns in Table 1 under the heading "Tsongas Data", using the following abbreviated headings:

Site No.:	Numerical coding of sites by Tsongas,
T to SS K-CO:	Time to steady-state CO concentration in kitchen (minutes, min),
SS K-CO:	Steady-state CO concentration in kitchen (parts-per-million, ppm),
Post SS K-CO:	Steady-state CO concentration in kitchen 15 minutes after oven off (ppm),
Peak X-CO:	Peak CO concentration in oven exhaust (ppm), and
SS X-CO:	CO concentration in oven exhaust at steady state kitchen CO (ppm).

The 6 major conclusions (C#) made from these field data by Tsongas were as follows:

C1) The average, steady-state CO concentration (SS K-CO) in the 60 kitchens was 29 ppm; the average CO concentration in oven exhausts at steady state (SS X-CO) was 101 ppm.

C2) On average, a SS K-CO of 9 ppm would result if the SS X-CO were 47 ppm, implying that ovens emitting >47 ppm CO could be dangerous.

C3) In ~50% (31/60) of the kitchens, the gas-fired ovens generated SS K-COs that exceeded the EPA exposure limit of 9 ppm for an 8-hour period.

C4) In ~15% (9/60) of the kitchens, the gas-fired ovens generated SS K-Cos that exceeded the EPA exposure limit of 35 ppm for a 1-hour period.

C5) Many kitchens exhibited little reduction in SS K-CO 15 minutes after the oven was turned off (Post SS K-CO), resulting in ~50% (29/60) still having CO above 9 ppm, and ~15% (9/60) above 35 ppm, levels that would persist for 8 hours or 1 hour, respectively.

C6) Gas-fired ovens were a "serious IAQ problem" in apartments.

The reviewer contends that Tsongas' conclusions are not supported by his field data. First, the method used to analyze the data is inappropriate statistically, and distorts their meaning. Second, the role of time in establishing exposure at any dosage of CO has been misrepresented. Third, the quality of the data is questionable. Regarding the last, however, the review assumed first that the data were reliable, despite skepticism that CO could reliably be measured to ±1 ppm over the 0-2000 ppm range with an inexpensive sensor. Not reproducing data from any one site also contributed to the skepticism.

Consider first Tsongas' use of arithmetic averaging. The results of doing so with the field data are given at the bottom of Table 1 as averages (AVG), and absolute (A; min or ppm) and relative (R; %) standard deviations (STD), For every data set except T to SS K-CO, standard deviations exceeded respective averages by factors of 1.4 to 2.6.

This extent of deviation indicates that the distribution of the data is skewed, that is, is not represented by a bell-shaped curve, which would disallow arithmetic averaging. Said in words, if arithmetic averaging were performed, a small number of high CO levels would obscure the significance of a much larger number of low CO levels. For example, for SS K-CO and Post SS K-CO data, 50 of the 60 sets are below their respective averages. The impact a small number of high CO levels can have is demonstrated by leaving out the highest value in the SS X-CO column, 2000 ppm for Site 3, which alone reduces the average from 101 to 69 ppm. Removing the next highest SS X-CO, 510 ppm, reduces its average to 61 ppm. Hence, averages reported by Tsongas are artificially high.

Because of the valid practical need to use all the field data collected, a more statistically appropriate method must be used to calculate averages that are numerically representative.

When field data, such as Tsongas', are skewed, a logarithmic transformation is performed to determine the geometric average of the distribution [1]. This transformation has been performed on all Tsongas' data, except T to SS K-CO, in the first 4 columns of Table 1 under "Reviewer Calculations". The geometric (G-) AVGs and ASTDs of the transformations are given below these 4 columns, followed by their (antilogarithm) conversion into an AVG, ASTD, and RSTD.

Proper statistical averaging of Tsongas' field data yields significantly different results, as follows:

The average steady-state CO concentration in the kitchen is 11 ppm, not 29 ppm,
The average post steady-state CO concentration in the kitchen is 10 ppm, not 23 ppm,
The average peak oven-exhaust CO concentration is 205 ppm, not 410 ppm, and
The average CO concentration in the oven exhaust at steady-state is 43 ppm, not 101 ppm.

This analysis reveals that the averages reported by Tsongas are 2-3 times lower than claimed (C1), making them much less "alarming". Moreover, this reanalysis did not account for two other apparent sources of CO-data inflation. First, Tsongas admits that his CO data were ~15% too high because of unaccounted for instrument interferences. Second, Tsongas attempted to generate worst-case (highest) CO emissions by operating the ovens on broil with the oven door closed. Tests elsewhere verify this assumption. Ovens of about the same vintage, with a similar time to steady state (30 minutes), and with the door closed, emitted an average, "as-measured" (Tsongas' "undiluted") CO of 48 ppm in the broil mode, and 38 ppm in the bake mode [2]. Hence, 43 ppm SS X-CO is the worst-case average.

With respect to C2, the correlation between SS K-CO and SS X-CO curve-fit by Tsongas predicts that the average SS X-CO of 43 ppm results in a SS K-CO of 8 ppm. This sub-9 ppm kitchen CO level suggests that in the average apartment tested, the average oven would emit safe levels of CO, even if operated for 8 hours, opposite to what Tsongas has concluded.

With respect to C3-C5, Tsongas misrepresents the connotation of dosage/time exposure for CO by focusing only on the dose element, 9 ppm or 35 ppm, and neglecting the time element, 8 or 1 hour(s), respectively. Tsongas did so by assuming, without proof, that SS K-Cos and Post SS K-Cos would persist for periods of 1 to 8 hours. This assumption can be shown to be invalid, as follows.

The analysis sought answers to 3 questions (Q). First (Q1), how long would a SS K-CO persist at or above 9 or 35 ppm in an apartment after the oven was turned off? Second (Q2), how long could an oven be operated in an apartment as a "space heater" before it achieved its purpose? Third (Q3), how do these times compare to 1 hour or 8 hours?

Tsongas provides qualitative and quantitative information with which to answer these questions. The former is in the form of the claim that the apartments were "leaky", although no support is given. The latter information is in the form of Post SS K-Cos that are less than SS K-Cos.

In answer to Q1, if the apartments were "leaky", SS K-Cos would not be expected to persist for "hours" after the oven was turned off, as entering outdoor air would dilute them to lower levels. Moreover, if SS K-Cos did persist for hours, the apartment would either have to be "tight", and contain all CO emitted before the oven was turned off, or the SS K-Cos would have to equal the background, or pre-test CO. Hence, apartments' being "leaky" seems incompatible with C5. If "leaky", the role of the background CO in determining the Post SS K-CO must be significant.

Knowing CO background levels, which were measured, but not reported, could resolve this paradox. How much does this background CO contribute to the Post SS K-CO? T1 reports that at one site (3), pre-test CO was 4 ppm, and outdoor CO 1 ppm. If these levels were typical, their contribution to Post SS K-Cos would be significant ($\geq$ 40%) for the 35 sites where these values were $\leq$10 ppm. Not properly accounting for the contribution of background CO levels may have significantly biased the conclusions, as would the $\pm$ 1 ppm accuracy in the measurement of Post SS K-CO.

Although background CO data would be valuable to know, their absence did not stymie the analysis. A first answer to this paradox is that 15 minutes was apparently not sufficient time to observe a falloff in CO concentration at 28 sites. However, 15 minutes was sufficient time in the other 22 sites to observe Post SS K-Cos less than SS K-Cos.

Continuing with Q1, the difference between SS K-CO and Post SS K-CO allows the calculation of the air changes per hour, ACH, a measure of "leakiness" (3). ACHs were calculated for the 22 sites with SS K-CO > Post SS-K CO (5th column under "Reviewer Calculations"), using the following:

$$\text{ACH (hour}^{-1}) = \frac{-\ln(\text{Post SS K-CO/SS K-CO})}{\text{Time (hours)}}$$

Calculated ACHs ranged from 5.9 hr^{-1} high (Site 3) to a non-zero low of 0.07 hr^{-1} (Site 52). Six sites (18, 37, 44, 52, 53, 54) had ACHs equal to or less than the ANSI/ASHRAE ventilation requirement (3) of 0.35 hr^{-1}. The geometric average of the ACHs is 0.6 hr^{-1}, which, according to the ANSI/ASHRAE requirement, could classify the average apartment tested as "leaky".

Knowing the ACH, the SS K-CO, and a target CO concentration that must not be exceeded for a specific duration (9 ppm/8 hours; 35 ppm/1 hour), the time required for the SS K-CO to decay to below the target-CO concentration can be calculated (Q3), as follows:

$$\text{Time (hours)} = \frac{-\ln(\text{Target CO/SS K-CO})}{\text{ACH (hour}^{-1})}$$

Table 1 lists the results under columns headed "T(ime) to 34 ppm" and "T(ime) to 8 ppm". At only 4 Sites (14, 16, 26, 52) would Post SS K-CO persist at $\geq$35 ppm for $\geq$1 hour. Likewise, at only 4 Sites (16, 26, 44, 52) would Post SS K-CO persist at $\geq$9 ppm for $\geq$8 hours.

These last findings indicate that Tsongas has overstated the alleged threat posed by gas-fired ovens. Of the 60 apartments tested, only 5 appear to have a problem (14, 16, 26, 44, 52). For 2 apartments (44, 52), their ACHs are below the ANSI/ASHRAE recommendation (0.35 hour^{-1}), indicating that they are too "tight", and that the problem is not with oven CO emissions, but with insufficient ventilation.

Note also that for Site 52, the Peak X-CO and SS X-CO are less than the SS K-CO and the Post SS K-CO, which again brings into question the reliability of the field data.

To answer Q2, consider the equation given in T1 relating the room CO concentration (C_r) to the air-free CO being generated (CO_a), volume of the flue gas per volume of fuel gas (V), exhaust gas flow rate (R, equal to the oven burner input rate (F) divided by the fuel heating value), time (t), dwelling air exchange rate (ach), and dwelling volume (v). The original use of this equation, derived in 1925 [4], was to calculate the temperature rise (dT) an appliance would cause if operated in a room. An ultra-conservative effective heat-transfer efficiency of 10% was assumed then, and now (oven door closed).

Using averages of parameters specific to the Tsongas field study, F = 15 KBtu/hr, ach = 0.56 hr^{-1} (calculated here), and v = 2424 ft^3 (303 ft^2 times 8 ft), the average times required to achieve certain temperature rises using the gas-fired oven as a space heater can be estimated. Given a reported outside temperature of 34 F (Site 3 in T1), and assuming a target indoor temperature of 75 F [5], Dt $\approx$ 40 F, and t $\approx$ 2.2 hours.

This calculation reveals that if the average oven were operated as intended (to broil) in the average apartment tested by Tsongas, it could be operated for only ~2 hours before its heating would become uncomfortable. Thus, in the 31 apartments tested where SS K-CO was $\leq$ 9 ppm, the time over which these levels could persist would never equal the required 8 hours of exposure, nullifying C3.

This calculation, however, appears to indicate that the 1-hour limit for exposure at 35 ppm would occur at 9 sites (3, 9, 14, 16, 26, 32, 41, 44, 52), verifying C4. However, at 5 of these apartments (16, 26, 32, 44, 52), the actual ACH in the apartment is less than the average ACH used in the calculation. Moreover, if the oven were intentionally used as a "space heater", the oven door would be open, greatly increasing the effective heat-transfer efficiency. Only a very plausible doubling of this efficiency, to ~20-25%, would be necessary to reduce the heating time to < 1 hour, indicating that the 35 ppm level of CO exposure would not persist for the required 1 hour.

Again, the number of sites that appear problematic is ~4 of the 60, and not ~30.

In summary, via more appropriate, extensive, and site-by-site analysis of the field data, specific and overall conclusions contrary to Tsongas' have been reached. That is, ovens do not appear to pose a "widespread" health threat with regard to exposure to CO emissions. The probability of posing a threat is more like ~5%, rather than 50%. Moreover, in these cases where a threat may be possible, it would be the apparent misuse of the oven (as a space heater) that would cause the threat.

REFERENCES

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4. Connor, R., "Carbon Monoxide Requirement for Gas Ranges", American Gas Association Testing Laboratory Report 516, December 14, 1925/January 6, 1926.

5. DeWerth, D., Borgeson, R., and Aronov, M., "The Effect of Properly Sized and Operated Vent-Free Gas Products on Indoor Air Quality", August, 1995.

TABLE 1. TSONGAS FIELD DATA AND REVIEWER CALCULATIONS

Tsongas Data						Reviewer Calculations						
SITE No. (#)	T to SS K-CO (min)	SS K-CO (ppm)	POST SS K-CO (ppm)	PEAK X-CO (ppm)	SS X-CO (ppm)	Log SS K-CO	Log POST SS K-CO	Log PEAK X-CO	Log SS X-CO	ACH (hr-1)	T to 34 ppm (hr)	T to 8 ppm (hr)
26	40	350	315	2000	510	2.5	2.5	3.3	2.7	.42	5.5	9.0
3	35	325	75	2000	2000	2.5	1.9	3.3	3.3	5.87	.4	.6
16	65	200	182	202	199	2.3	2.3	2.3	2.3	.38	4.7	8.5
52	50	119	117	106	106	2.1	2.1	2.0	2.0	.07	18.5	39.8
14	45	94	73	2000	250	2.0	1.9	3.3	2.4	1.01	1.0	2.4
41	35	64	50	2000	120	1.8	1.7	3.3	2.1	.99	.6	2.1
32	35	48	42	2000	40	1.7	1.6	3.3	1.6	.53	.6	3.4
9	45	43	34	1170	157	1.6	1.5	3.1	2.2	.94	.3	1.8
44	105	36	35	120	101	1.6	1.5	2.1	2.0	.11	.5	13.3
1	40	26	20	300	250	1.4	1.3	2.5	2.4	1.05	.0	1.1
55	40	26	20	280	95	1.4	1.3	2.4	2.0	1.05	.0	1.1
43	90	22	22	675	120	1.3	1.3	2.8	2.1		.0	
53	35	21	20	280	96	1.3	1.3	2.4	2.0	.20	.0	4.9
50	30	19	16	640	54	1.3	1.2	2.8	1.7	.69	.0	1.3
60	55	18	18	330	75	1.3	1.3	2.5	1.9		.0	
54	40	17	16	2000	150	1.2	1.2	3.3	2.2	.24	.0	3.1
45	20	17	15	780	100	1.2	1.2	2.9	2.0	.50	.0	1.5
38	45	16	16	300	220	1.2	1.2	2.5	2.3		.0	
51	20	16	16	145	87	1.2	1.2	2.2	1.9		.0	
48	35	16	16	129	45	1.2	1.2	2.1	1.7		.0	
31	45	15	15	350	64	1.2	1.2	2.5	1.8		.0	
37	30	14	13	390	22	1.1	1.1	2.6	1.3	.30	.0	1.9
39	75	14	14	170	104	1.1	1.1	2.2	2.0		.0	
47	35	14	12	30	10	1.1	1.1	1.5	1.0	.62	.0	.9
18	40	12	11	475	20	1.1	1.0	2.7	1.3	.35	.0	1.2
59	35	10	6	265	85	1.0	.8	2.4	1.9	2.04	.0	.1
5	60	10	10	200	53	1.0	1.0	2.3	1.7		.0	
20	65	10	10	179	38	1.0	1.0	2.3	1.6		.0	
46	40	10	10	112	24	1.0	1.0	2.0	1.4		.0	
42	30	9	8	460	41	1.0	.9	2.7	1.6	.47	.0	
36	35	9	9	375	16	1.0	1.0	2.6	1.2		.0	
12	50	8	8	49	36	.9	.9	1.7	1.6		.0	.0
19	35	7	7	350	32	.8	.8	2.5	1.5		.0	.0
24	40	7	7	134	9	.8	.8	2.1	1.0		.0	.0
34	35	7	7	45	17	.8	.8	1.7	1.2		.0	.0
29	35	6	6	100	48	.8	.8	2.0	1.7		.0	.0
13	35	6	6	75	18	.8	.8	1.9	1.3		.0	.0
30	30	6	6	28	29	.8	.8	1.4	1.5		.0	.0
56	30	6	5			.8	.7			.73	.0	.0
11	45	5	5	239	13	.7	.7	2.4	1.1		.0	.0
4	30	5	5	230	20	.7	.7	2.4	1.3		.0	.0
22	30	5	5	153	15	.7	.7	2.2	1.2		.0	.0
40	20	5	5	135	10	.7	.7	2.1	1.0		.0	.0
58	40	5	5	113	15	.7	.7	2.1	1.2		.0	.0
49	35	5	5	85	24	.7	.7	1.9	1.4		.0	.0
21	45	5	5	67	35	.7	.7	1.8	1.5		.0	.0
33	40	5	5	50	45	.7	.7	1.7	1.7		.0	.0
57	20	5	5	12	10	.7	.7	1.1	1.0		.0	.0
10	35	4	3	338	23	.6	.5	2.5	1.4	1.15	.0	.0
23	20	4	4	270	19	.6	.6	2.4	1.3		.0	.0
25	30	4	4	109	20	.6	.6	2.0	1.3		.0	.0
28	30	4	4	75	36	.6	.6	1.9	1.6		.0	.0
35	20	4	4	48	8	.6	.6	1.7	.9		.0	.0
6	35	3	3	266	55	.5	.5	2.4	1.7		.0	.0
8	35	3	3	230	55	.5	.5	2.4	1.7		.0	.0
15	40	3	3	162	4	.5	.5	2.2	.6		.0	.0
7	40	3	3	122	18	.5	.5	2.1	1.3		.0	.0
27	30	3	3	95	80	.5	.5	2.0	1.9		.0	.0
17	35	3	3	67	25	.5	.5	1.8	1.4		.0	.0
2	40	3	3	60	8	.5	.5	1.8	.9		.0	.0
					G-AVG	1.0	1.0	2.3	1.6			
					G-ASTD	.5	.5	.5	.5			
AVG	40	29	23	410	101	11	10	205	43	.56		
ASTD	15	65	48	571	263	3	3	3	3			
RSTD (%)	38	223	209	139	259	28	28	2	7			

APPENDIX 2.

TECHNICAL REVIEW OF REFERENCE 18 (CARNOW)

TECHNICAL REVIEW OF PAPER BY CARNOW: CO EMISSIONS FROM GAS-FIRED OVENS

February 8, 1996

A technical review is offered on the following paper:

Conibear, S., Geneser, S., and Carnow, B.,, "Carbon Monoxide Levels and Sources Found in a Random Sample of Households in Chicago During the 1994-1995 Heating Season", ASHRAE IAQ, November, 1995.

The following observations were made:

1) As did Tsongas[1], Carnow (erroneously) ignores the role of TIME in the dose/exposure relationship for CO health and safety. Ambient CO exceeded 9 ppm in only 2 of 84 sites before the gas appliances were used (Table 2), and in only 10 of 84 sites after a gas appliance was on for 1 hour (Table 3). The information missing is how long it took for the elevated levels in Table 3 to return to the background levels of Table 2. If this time is >8 hours, then there may be health threat from ambient CO. If this time is <8 hours, there is no CO exposure problem. Data in the paper may answer this question. 12 ovens and 1 stove emitted peak or steady-state CO levels >500 ppm (Table 4), whereas in only 10 sites did the ambient CO exceed 9 ppm (Table 3). This implies high air exchange rates, which could dissipate rather large levels of CO. Hence, the ambient levels would not persist for 8 hours.

2) One possible source of (large) error involves how oven exhausts were sampled "near the appliance" (Table 4), which is not the ANSI method (Table 7). The suspicion is that mixing of the combustion products in the "near" location would be sufficiently poor to cause a single-point sample to be not representative of the total exhaust. A spatially integrated sample must be taken to get a representative level of CO. Table 4 data may, therefore, be biased high.

3) Carnow measured comparable magnitudes for the average peak and steady-state values for CO near the oven (188 vs. 145 ppm), whereas others have measured factors of 5 [1]. This seems to indicate that the CO monitor used may have been saturated upon one measurement, and not allowed to equilibrate before the next measurement.

4. As with Tsongas'[1], Carnow's data have been averaged arithmetically, which is statistically invalid given that their standard deviations are equal in magnitude with the averages. The true (geometric) average of as-measured CO for ovens is 138, not 166 ppm.

5. Despite the (obvious) error in the equation used to normalize as-measured CO data to an O_2-free basis, Carnow seems to have performed the normalization correctly. The data in Figure 1 can be used to calculate the normalization factor, which in turn can be used to estimate the as-measured CO_2. The average CO_2 from this data extraction is $\sim 2\%$, which seems low for ovens, but is the correct order-of-magnitude (%). Other evidence that the CO and CO_2 field data given in Table 7 are suspect rests with the fact that two ovens (#7 and #20) emitted the same CO_2, 0.84%, but an order-of-magnitude different CO, 360 and 5525 ppm, respectively.

REFERENCES:

1. Tsongas, G. and Hager, W., "Field Monitoring of Elevated Carbon Monoxide Production from Residential Gas Ovens", ASHRAE IAQ, November, 1994.